SMC Laser Injury Event

Level 1 Cause Analysis in Support of

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Idaho National Laboratory
Specific Manufacturing Capability (SMC)
Idaho Falls, Idaho 83415

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INL/INT-11-23268

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EXECUTIVE SUMMARY

An SMC technician received 2nd degree burns to the middle and ring fingers of his left hand while performing a preventive maintenance (PM) procedure on a Class IV industrial laser August 30, 2011. The task required placement of a "target" in the beam path to verify mirror alignment. The technician, believing the laser was in a safe mode, reached into the beam pathway to place the target, saw a flash and immediately withdrew his hand.

Three SMC technicians were assigned to perform a 2000 hour run time PM on the Line 9 laser. A pre-job briefing was held August 29, 2011 by the acting foreman and the technicians started the PM. They had completed 25 steps in Section I of the work order by the end of the day. The laser systems were placed under LO/TO and the internal optics were cleaned and/or replaced. The LO/TO was released and the next morning, August 30, 2011, the technicians prepared to take a diagnostic shot inside the internal optics.

The laser was powered up at the HMI, and the person in charge (PIC) selected the "Mirror Alignment" program from the human machine interface (HMI) screen, enabled the pendent and pressed the "Cycle Start" button. The technicians believed the laser was in "simmer" mode at this point and that no beam was being generated out of the resonator. A beam was being generated in the "Mirror Alignment" program when the "Cycle Start" button was pressed. They decided to check the #4 aperture target and see if they were aligned at that location. One of the technicians reach to place the target at the end of the Z box and a "Flash" occurred. The technician immediately retracted his hand with the target.

The PIC turned off the high voltage (HV) at the pendent. The Foreman and Supervisor were informed of the incident and the injured technician was escorted to TAN Medical. The nurse evaluated the injury and sent the technician to CFA for further evaluation. CFA Medical examined the technician's hand. The technician's left middle and ring fingers received 2nd degree burns to both finger tips. A prescription burn ointment and bandage was applied. The employee was returned to work with no restrictions.

The significant issues identified through this investigation were:

Training

Training or training retention lacked key safety concepts. Some of the technicians lacked a thorough understanding of the HMI program screen functions and the "simmer" mode of laser operation.

Work Order Planning

The work order did not provide specific controls required to safely perform the alignment task.

Worker Performance

Portions of the task were performed from memory rather than referencing an approved procedure or vendor manual. The technicians did not follow the vendor recommended safe work practices.

Hazard Analysis

Safety, the Laser Safety Officer (LSO) and Engineering relied on the technician's skill, training and experience to perform the tasks safely. Supervision, Safety, LSO, and Engineering personnel did not pursue further understanding of the system and did not require the work order to identify specific controls to perform the work safely. These support personnel did not follow through with research and monitoring of work activities to verify the actions taken by the technicians were appropriate for the level of risk.

The fundamental issue with the first line of defense (people) of this event is that all personnel are fallible and even the best will make mistakes. Errors are likely when individuals rely on past successes instead of verifying and following a prescribed protocol.

The fundamental issue with the second line of defense (organization and programs) of this event is the inadequate work direction, relying on the technician's skill, training and experience rather than establishing appropriate work control for the process.

CONTENTS

ACRONYMS

BEA	Battelle Energy Alliance, LLC
CF	causal factor
E&CF	Events and Causal Factors Chart
HMI	Human Machine Interface
INL	Idaho National Laboratory
ISMS	Integrated Safety Management System
LO/TO	Lockout/tagout
LSO	Laser Safety Officer
LTA	less than adequate
NTS	Noncompliance tracking system
PM	preventive maintenance
PPE	personal protective equipment
SMC	Specific Manufacturing Capability
TAN	Test Area North
WO	work order

SMC Laser Injury Event

1. BACKGROUND

The SMC project utilizes several Class IV industrial lasers to fabricate components from various types of materials. These laser systems require maintenance, including optics cleaning, replacement and alignment in order to properly perform their function.

The Line 9 Cincinnati CL-707 laser was installed in 2005. This laser system is composed of three basic components:

1. Beam generator (resonator) built by Rofin, this portion of the laser system contains the electrodes, rear mirror, output mirror, diamond window, bending mirror, spherical mirror, spatial filter, cylindrical mirror, power mirror and shutter (beam dump). This portion is referred to as the "internal optics." This portion of the beam is "unfocused" and is available whenever high voltage (HV) is applied to the electrodes with enough energy to produce photons.
2. The Cincinnati portion includes the beam delivery optics, laser head, gantry, table, HMI and pendant. This portion is referred to as the "external optics."
3. Material handling system including vacuum transporters, overhead gantry, scrap fork and transfer table. This system has no laser components.

Approximately ten individuals at SMC have received training on the Rofin and/or Cincinnati components at the factory. Most of these individuals are electrical technicians, although a few are component engineers and work planners. Some individuals have Rofin training, some have Cincinnati and some have both. The training is specific to that basic component. In other words, Rofin training only covers those components within the resonator cabinet. Cincinnati training covers those components downstream of the shutter, including the beam delivery systems and laser head. The most recent training took place in May 2010 on the Rofin components. Factory representatives have been out to SMC to work on lasers and technicians have had the opportunity to observe and learn from them. As a note, the manufacturer recommends re-training between 18 and 24 months.

The manufacturer recommends various preventive maintenance (PM), including the 2000 hour runtime PM. The PM is performed per Planned Work Order # 80021212, Line 9 Electrical 2000 Hr. Run Time PM's and includes items like:

1. Laser Cooling System checks
2. Laser head inspect and clean
3. Ball screw lubrication
4. Electrical connections
5. Laser gas leak testing
6. Vacuum test
7. Alignment tests
8. RF tube current
9. Mode burns
10. Safety mats inspections
11. Gantry material handling system

12. Four corner card shots

13. Beam delivery alignment

The “pendant” is a device that allows the technicians to maintain exclusive control of the HMI when physically separated from the controller. The pendant can be “enabled” which removes control capabilities from the HMI console, allowing the technicians to take the controls with them as they perform tasks on the laser system.

Section II of the WO addresses hazards and controls such as electrical arc flash and shock, mechanical motion of the gantry, table and laser head, high power invisible laser beam, chemicals, pinch points and sharp edges, pressurized gasses, noise, and elevated work. Controls include LO/TO, training, exclusive control of the pendent, PPE, barriers and signs. This work order references various sections and procedures from the manufacturer’s vendor data.

2. SCOPE OF THIS INVESTIGATION

This investigation and cause analysis is limited to the events leading up to and directly influencing the unexpected equipment status where the employee came into contact with an unfocused Class IV laser beam. This investigation covered the activities associated with the laser maintenance regarding optics, alignment, and beam quality. The intent of this investigation is to establish the facts and determine causes that contributed to the unexpected contact with an exposed laser beam. This cause analysis will be used to develop corrective actions addressing the issues identified.

3. FACTS

3.1 Chronology of Activities

5/10 Approximately 10 SMC personnel attended Rofin training off-site.

6/10 Laser Safety Officer (LSO), Safety, Engineering and Maintenance evaluate the PM activities and develop hazard controls to be incorporated into the work order.

8/11 SMC technicians perform the Line 7 2000 hr. PM., which includes internal optics work.

NOTE: *This laser and the PM are nearly identical to the work that was to be performed on Line 9.*

<u>8/29/11</u>

Pre-job briefing by acting Foreman. Identify three technicians to perform the Line 9, 2000 hr. run time PM and name the person in charge (PIC). The technician perform Steps 1-24 in Section I.

<u>8/30/11</u>

0800 Performed paper shot in Step 25, Section I. The shot is taken downstream of the shutter. The PIC selected the “Mirror Alignment” screen on the HMI and enters/verifies the parameters. He then enables the pendent and presses “Cycle Start”. The PIC uses the pendent to flash the shutter and take the shot. The shot indicates the internal optics (Rofin) need some attention.

NOTE: *It is important to understand the difference between shots taken upstream and downstream of the shutter. In this mode, once “Cycle Start” is pressed, a beam is generated and present in the internal optics (Rofin) portion of the laser. The shutter (beam dump) controls the beam entering the external optics (Cincinnati) portion.*

0900 Placed the laser system under LO/TO.

0930 Removed the Z box cover. Inspect cylindrical, spherical and power mirrors. Identified burn spots on the cylindrical and power mirrors. Replace cylindrical and power mirrors and clean the spherical mirror. Reinstall all the mirrors in the holders.

1020 Removed the LO/TO.

1030 Powered up the laser system. Cleared the alarms and home the laser.

1040 PIC selected "Mirror Alignment" program from the HMI screen, enables the pendent and presses the "Cycle Start" button.

NOTE: *The technicians believed the laser was in "simmer" mode at this point and that no beam was being sent out of the resonator. In the "Mirror Alignment" program with the "Cycle Start" button pressed, a beam was being generated. Indicators of an active beam include, the screen says "Beam On", wattage indicates 2500 watts, the red light on top of the laser gantry indicates high voltage is on, and the resonator sight glass is glowing.*

1046 Technicians access the resonator platform and discuss where to start taking cross hair shots. Decided to check the #4 aperture target and see if they were aligned at that location.

1050 Technician #1 reaches to place the target at the end of the Z box and a "Flash" occurred which they all saw. The technician immediately retracts his hand with the target.

1055 The PIC turns off the HV at the pendent and all three technicians exit from the platform. The Foreman and Supervisor are informed of the incident and the injured technician was escorted to TAN Medical.

1100 The TAN nurse evaluates the injury and send the technician to CFA for further evaluation.

1230 CFA Medical examines the technician's hand. The technician's left middle and ring fingers received 2nd degree burns to both finger tips. A prescription burn ointment and bandage was applied. The employee is returned to work with no restrictions.

1500 Critique was held.

1830 The laser is secured and left for the night.

3.2 Analysis

Two analysis techniques are used in this investigation, an Event and Causal Factors Analysis and Barrier analysis. In addition, a Human Performance Matrix, attached in Appendix C is included. The results of this analysis are summarized within the context of the 5 core Integrated Safety Management System (ISMS) guiding functions below.

3.2.1 Core Function 1 – Define the Scope of Work

Missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.

The high level scope was to perform the 2000 hr. PM as suggested by the manufacturer. From the perspective of the technicians, the scope was well defined and understood. They had worked the task before and had a good understanding of what was required to complete the task

<u>This core function was met.</u>

3.2.2 Core Function 2 – Analyze the Hazards

Hazards associated with the work are identified, analyzed, and categorized.

A significant effort was made in the spring of 2010 to evaluate the hazards associated with laser maintenance. This effort reviewed the existing work order, observed some of the laser maintenance tasks that were ongoing at that time and reviewed LO/TO practices. The LSO, Component Engineer and Safety Engineer were extensively involved with this evaluation. The hazard evaluation focused on those tasks that required LO/TO. Some tasks (alignment) must be performed with power available to maintain temperature equilibrium within the optics. Specific controls for these tasks were not identified and documented in the WO. There was an excessive reliance on the skill, training and experience of the technicians to perform the tasks safely.

This core function was not fully met.

3.2.3 Core Function 3 – Develop and Implement Hazard Controls

Applicable standards and requirements are identified and agreed-upon, controls to prevent/mitigate hazards are identified, the safety enveloped is established, and controls are implemented.

From the work order planning perspective, the details of the task were not fully defined. As a result, during the analysis of hazards and identification of controls, specific information affecting the safe execution of the task was not defined.

The hazard controls that were developed and implemented through the work order were based on LO/TO. Since several of the tasks were never observed or discussed, some specific controls for live work were not recognized or implemented. Some of these controls such as, turning off HV, checking the beam path with thermal paper prior to placing hands were identified in the manufacturer's training and/or procedures, but were not referenced or incorporated into the work order.

This core function was not fully met.

3.2.4 Core Function 4 – Perform Work within Controls

Readiness is confirmed and work is performed safely.

The work order contains a good, but not complete set of hazards and controls. Some specified controls such as LO/TO for mirror replacement, set-up a laser control area (LCA), and maintain exclusive control for mechanical motion were followed. Others such as adjust laser to low power, keep body parts clear of the beam path, and wear laser safety glasses when there is an exposed beam were not followed. Less specific controls such as following safety training and using reference materials from the vendor were not followed.

This core function was not fully met.

3.2.5 Core Function 5 – Provide Feedback and Continuous Improvement

Feedback information on the adequacy of controls is gathered, opportunities for improving the definition and planning of work are identified and implemented, line and independent oversight is conducted, and, if necessary, regulatory enforcement actions occur.

Prior to this event, the controls appeared to be adequate. The technicians had performed the same task a few weeks prior with no problems. Maintenance management was unaware of any concerns or difficulty following the work control. Safety and the LSO were not aware of any difficulty maintaining compliance with the controls or that the controls were inadequate.

This core function was met.

4. CONCLUSIONS

The direct cause of this event was the misunderstanding regarding the beam functions while in the program screen "Mirror Alignment." As in most events, it's not just one barrier that fails, it's several. The technicians had received the training and had enough experience to perform the task safely, but did not follow some key safe work practices such as turning off HV, and checking the beam path with paper prior to placing the target. The work order lacked critical instructions regarding the task and did not reference the specific Rofin procedure for this task; as a result the technicians performed the task from memory. The hazard assessment relied on the training and experience of the technicians and did not follow-up to verify the effectiveness and implementation of controls.

The lessons learned from this event should be used to raise the awareness levels of all individuals within BEA who are responsible to plan, oversee, or review work involving lasers. Unfortunately, many barriers failed at the same time.

Training Issues

CF-1 A6, B3, C02, Inadequate training content.

1. The vendor training was conducted using a machine interface and program (Rofin) that was not the same one available to the technicians at SMC (Cincinnati). As a result the technicians were confused regarding the effects of the program screen they used. The "Mirror Alignment" screen they were using flashes the shutter, whereas the "Resonator Service" screen flashes the resonator. The technicians were more comfortable accessing the mirror alignment screen, although from a safe work practice, it was not the preferred method.
2. The technicians performing the PM had a misunderstanding regarding the use of "Simmer" mode. It was believed that since no beam was being generated in this mode, the beam path could be accessed with no further precautions. This belief appears to have been created through a combination of circumstances. First, when working on the Cincinnati (external) portion of the beam path, the shutter prevents the beam from entering the delivery system. Therefore there would be a level of protection preventing a beam presence in the path. Second, when the technicians had performed cross hair shots in the past in the internal (Rofin) portion upstream of the shutter, there is not a beam present prior to and after taking a shot, as evidenced by the paper target inserted. Once high voltage is applied, a simple command from the controller will send a beam through the internal optics. The Rofin training and procedures always required the high voltage to be off prior to placing any portion of the body in the beam path.
3. Although Electrical and laser operator training was identified and required to perform the tasks of the work order, the specialized vendor training courses, retraining requirements and methods of tracking the training were not defined. The work order did not recognize the difference between Rofin and Cincinnati training.

Work Order Planning Issues

CF-2 A4, (Management Problem) B3, (Work Organization) C11, Inadequate work package planning.

1. The hazard identification process relied on the skill, training and experience of the technicians and did not identify some important safety rules established by the manufacturer. As such, the work order lacked specific controls required to safely perform the task.
2. Work order 80021212 did not provide a through set of work instructions, specific hazard controls, or references to perform the tasks safely. The work order relied on specialized training rather than establishing specific instructions for the technicians to follow.

3. Applicable vendor data was not incorporated or referenced in the work order.
4. Section I, Step 26 did not provide adequate instruction, reference the vendor data or discuss the applicable safety requirements to perform the task.

Worker Performance Issues

CF-3 A3 (Human Performance), B2, (Rule Based Error), C04, Previous success in use of the rule reinforced continued use of the rule.

1. The technicians performed portions of the task from memory rather than reference the work order or Rofin vendor manual and procedure VA-19-01-33. Key safety steps (turn off the high voltage prior to placing any part of the body in the beam path) were not performed correctly.
2. Vendor training encouraged the practice of inserting a piece of thermal paper into the beam path to verify the beam was not present prior to placing any part of the body in the beam path. This practice has not been followed at SMC for some time.
3. The technicians had developed a level of confidence based on their experience with lasers at SMC. In some cases, this confidence led to a departure from safe work practices encouraged at the vendor training.

Hazard Analysis Issues

CF-4 A4, B1, C04, Management follow-up or monitoring of activities did not identify problems.

1. During the hazard assessment the support team (Safety, LSO, and Engineering) relied on the technician's skill, training, and experience to perform the tasks safely. After the work order was issued, these support personnel did not follow through with research and monitoring of work activities to verify the actions taken by the technicians were appropriate for the level of risk.
2. The Risk Assessment relied on expert based controls vs. standards based controls. There was no oversight of these controls to verify consistency or effectiveness. When non-standard controls are used, the effectiveness of those controls must be confirmed. In this case, follow-up monitoring to verify the work was being performed in a safe and compliant manner was not performed.

5. RECOMMENDATIONS

The responsible manager will use this cause analysis to develop corrective actions addressing the broad range of issues identified. This action will be tracked to completion in ICAMS IO-008197.

The following general recommendations are made:

- Perform an Extent of Condition analysis to evaluate work orders which incorporate vendor procedures to ensure they have adequate hazard analysis and controls included.
- Verify work orders contain adequate work instructions and specific safety controls such as verify HV off, insert thermal paper to allow the performance of tasks without relying on memory or higher-order skills.
- Provide training, on SMC specific equipment, to those technicians performing PM's and repairs on the lasers.
- Perform management observations to enforce the use of work orders, procedures and vendor data when performing tasks requiring specific safety controls.

- Provide personnel, who understand the hazards and methods of control to perform risk assessment and hazard analysis for laser systems.
- Issue a lessons learned to the laser user community.
- Although not causal to this event, two issues were identified during the investigation which need to be corrected:
    1. Clarification on when and where the use of laser safety glasses is required,
    2. Tasks not specifically described in the work order steps were performed based on activities listed in the hazard and mitigations section.

6. APPENDIXES

Appendix A, Barrier Analysis

Appendix B, Human Performance Matrix

Appendix C, Causal Factor Flow Chart

Appendix D, Photographs

Appendix A

Barrier Analysis

Barrier	Purpose Of Barrier	Performance of Barrier
FAILED BARRIERS		
Training	Ensure work is performed by personnel trained, knowledgeable and qualified.	**CF-1 A6, B3, C02, Inadequate training content.** The vendor training was conducted using a machine interface and program (Rofin) that was not the same one available to the technicians at SMC (Cincinnati). As a result the technicians were confused regarding the effects of the program screen they used. The “Mirror Alignment” screen they were using flashes the shutter, whereas the “Resonator Service” screen flashes the resonator. The technicians were more comfortable accessing the mirror alignment screen, although from a safe work practice, it was not the preferred method.
	Ensure work is performed by personnel trained, knowledgeable and qualified.	The technicians performing the PM had a misunderstanding regarding the “Simmer” mode. It was believed that since no beam was being generated in this mode, the beam path could be accessed with no further precautions. This belief appears to have been created through a combination of circumstances. First, when working on the Cincinnati (external) portion of the beam path, the shutter prevents the beam from entering the delivery system. Therefore, in simmer mode, there would be a level of protection preventing a beam presence in the path. Second, when the technicians had performed cross hair shots in the internal (Rofin) portion upstream of the shutter, there had not been a beam present prior to and after taking a shot, as evidenced by the paper target inserted. The fact is there is nothing to prevent a beam in the internal optics portion once high voltage is applied. The Rofin training and procedures always required the high voltage to be off prior to placing any portion of the body in the beam path.
	Ensure work is performed by personnel trained, knowledgeable and qualified.	Although Electrical and laser operator training was identified and required to perform the tasks of the work order, the specialized vendor training courses, retraining requirements and methods of tracking the training were not defined. The work order did not recognize the difference between Rofin and Cincinnati training.

Barrier	Purpose Of Barrier	Performance of Barrier
Work Order Planning	Establish consistent methods for safe, compliant work by utilizing maintenance work orders to state the scope, identify hazards and establish controls.	**CF-2 A4, B3, C11, Inadequate work package planning.** The hazard identification process relied on the training and knowledge of the technicians and did not identify some important safety rules established by the manufacturer. As such, the work order lacked specific controls required to safely perform the task.
	Establish consistent methods for safe, compliant work by utilizing maintenance work orders to state the scope, identify hazards and establish controls.	Work order 80021212 did not provide a through set of work instructions, specific hazard controls, or references to perform the tasks safely. The work order relied on specialized training rather than establishing specific instructions for the technicians to follow.
	Establish consistent methods for safe, compliant work by utilizing maintenance work orders to state the scope, identify hazards and establish controls.	Section I, Step 26 did not provide adequate instruction, reference the vendor data or discuss the applicable safety requirements to perform the task.
Worker Performance	Maintain skills and knowledge to safely perform assigned tasks. Implement safe work practices as directed by supervision, training, procedures and work control.	**CF-3 A3 (Human Performance), B2, (Rule Based Error), C04, Previous success in use of the rule reinforced continued use of the rule.** The technicians performed portions of the task from memory rather than reference the work order or Rofin vendor manual and procedure VA-19-01-33. Key safety steps (turn off the high voltage prior to placing any part of the body in the beam path) were not performed correctly.
	Implement safe work practices as directed by supervision, training, procedures and work control.	Training encouraged the practice of inserting a piece of thermal paper into the beam path to verify the beam was not present, prior to placing any part of the body in the beam path. This practice has not been followed at SMC for some time.
	Implement safe work practices as directed by supervision, training, procedures and work control.	The technicians had developed a level of confidence based on their experience with lasers at SMC. In some cases they departed from safe work practices encouraged at the vendor training.

Barrier	Purpose Of Barrier	Performance of Barrier
Hazard Analysis	Decisions are made at the appropriate level with buy-in from Engineering, Safety, and Maintenance supervision. Identify hazards, develop controls, and work within those controls.	**CF-4 A4, B1, C04, Management follow-up or monitoring of activities did not identify problems**. During the hazard assessment the support team (Safety, LSO, and Engineering) relied on the technician's skill, training, and experience to perform the tasks safely. After the work order was issued, these support personnel did not follow through with research and monitoring of work activities to verify the actions taken by the technicians were appropriate for the level of risk.
	Hazards are identified and mitigated in the work control documents.	The Risk Assessment relied on expert based controls vs. standards based controls. There was no oversight of these controls to verify consistency or effectiveness.

Appendix B

Human Performance Improvement Matrix

Cause or LTA Behavior	Who/What	Expected Behavior	Actual Behavior	Why the Behavior Made Sense at the Time
CF-1 The vendor training was conducted using a machine interface and program (Rofin) that was not the same one available to the technicians at SMC (Cincinnati). As a result the technicians were confused regarding the effects of the program screen they used. The "Mirror Alignment" screen they were using flashes the shutter, whereas the "Resonator Service" screen flashes the resonator. The technicians were more comfortable accessing the mirror alignment screen, although from a safe work practice, it was not the preferred method.	Technicians	The technicians will use the proper screen and program to perform the required tasks. In this case the proper screen would be the resonator service screen. If there is confusion, the technicians should stop work.	There was a misunderstanding regarding the mode of operation once "cycle start" was pushed. The "Mirror Alignment" screen they were using flashes the shutter, whereas the "Resonator Service" screen flashes the resonator. The technicians were more comfortable accessing the mirror alignment screen, although from a safe work practice, it was not the preferred method.	The technicians knew there was a difference between the interface program they had trained on and the actual Cincinnati interface on the SMC lasers. They had been shown a screen by a factory service technician that would allow them access to the mirror alignment screen and they believed, based on past successes, they understood the function.

Cause or LTA Behavior	Who/What	Expected Behavior	Actual Behavior	Why the Behavior Made Sense at the Time
The technicians performing the PM had a misunderstanding regarding the “Simmer” mode. It was believed that no beam was being generated in this mode and the beam path could be accessed with no further precautions.	Technicians	The technicians are expected to always verify there is no beam before entering the beam path.	The technicians were placing targets (with their fingers) into the beam path with the high voltage on.	This belief appears to have been created through a combination of circumstances. First, when working on the Cincinnati (external) portion of the beam path, the shutter prevents the beam from entering the delivery system. Therefore, in simmer mode, there would be a level of protection preventing a beam presence in the path. Second, when the technicians had performed cross hair shots in the internal (Rofin) portion upstream of the shutter, there had not been a beam present prior to and after taking a shot, as evidenced by the paper target inserted.
Specialized vendor training courses, retraining requirements and methods of tracking the training were not defined.	Maintenance Management	Identify and document the specific training required to perform maintenance on the laser systems.	The training requirements were loosely described in the work order.	It was believed the factory training from either Rofin or Cincinnati provided the necessary understanding of the systems and safety features.

Cause or LTA Behavior	Who/What	Expected Behavior	Actual Behavior	Why the Behavior Made Sense at the Time
CF-2 The hazard identification process relied on the training and knowledge of the technicians and did not identify some important safety rules established by the manufacturer. As such, the work order lacked specific controls required to safely perform the task.	Planner LSO Safety Engineer	Establish specific controls based on the hazards present. The controls need to be incorporated into the work order steps.	The hazard identification process did not take the time or effort to fully understand the safety practices required to safely perform the task.	The laser systems are complex and require specialized training and experience. At the time the hazard analysis was performed, the technicians had the most training and experience on these systems.
Work order 80021212 did not provide a thorough set of work instructions, specific hazard controls, or references to perform the tasks safely. The work order relied on specialized training rather than establishing specific instructions for the technicians to follow.	Planner Engineer Technicians	Establish specific controls based on the tasks. The work instructions need to be incorporated into the work order steps, or the vendor data should be referenced to be used.	Specific steps in the work order were lacking instructions necessary to perform the task. A specific vendor procedure that should have been followed was not incorporated or referenced. This resulted in the technicians performing the task from memory.	The task variables were considered too restrictive for step by step instructions in the work order. Therefore, skill, knowledge, and training was relied upon rather than using detailed work direction.
Applicable vendor data was not incorporated or referenced in the work order.	Engineer Planner	The work instructions need to be incorporated into the work order steps, or the vendor data should be referenced to be used.	A specific vendor procedure that should have been followed was not incorporated or referenced.	The vendor procedure did not follow INL LO/TO standards and therefore was not considered acceptable work control.
Section I, Step 26 did not provide adequate instruction, reference the vendor data or discuss the applicable safety requirements to perform the task.	Engineer Planner	The work instructions need to be incorporated into the work order steps, or the vendor data should be referenced to be used.	A specific vendor procedure that should have been followed was not incorporated or referenced.	The vendor procedure did not follow INL LO/TO standards and therefore was not considered acceptable work control.

Cause or LTA Behavior	Who/What	Expected Behavior	Actual Behavior	Why the Behavior Made Sense at the Time
CF-3 The technicians performed portions of the task from memory rather than reference the work order or Rofin vendor manual and procedure VA-19-01-33. Key safety steps (turn off the high voltage prior to placing any part of the body in the beam path) were not performed correctly.	Technicians	Perform tasks in accordance with the work instructions, referenced vendor data and training.	The technicians were performing work steps from memory, without the aid of work instructions, or vendor data. As a result some key safety practices were missed.	There were no work instructions in the work order.
Training encouraged the practice of inserting a piece of thermal paper into the beam path to verify the beam was not present, prior to placing any part of the body in the beam path. This practice has not been followed at SMC for some time.	Technicians	Understand and follow the training provided to ensure maximum safety.	The practice of using an indicator in the beam path prior to inserting their hands has not been practiced at SMC for years.	When the technicians had performed cross hair shots in the internal (Rofin) portion upstream of the shutter, there had not been a beam present prior to and after taking a shot, as evidenced by the paper target inserted. This led to a belief that it was not necessary to insert another piece of paper.
The technicians had developed a level of confidence based on their experience with lasers at SMC. In some cases they departed from safe work practices encouraged at the vendor training.	Technicians	Understand and follow the training specific to the portion of the laser system they are working on (Rofin vs. Cincinnati) to ensure maximum safety.	Their experience at SMC had led to a level of confidence and beliefs which drifted from practices and procedures learned in the vendor training.	They had been successful numerous times in the past working on the Cincinnati portion, using the same methods.

Cause or LTA Behavior	Who/What	Expected Behavior	Actual Behavior	Why the Behavior Made Sense at the Time
CF-4 The technicians convinced support personnel the training provided the necessary knowledge and understanding to perform the tasks safely. Supervision and support personnel accepted the training and did not pursue further understanding of the system and specific controls that were required to perform the work safely. The support personnel did not follow through with research and monitoring of work activities to verify the actions taken by the technicians were appropriate for the level of risk.	Maintenance Supervision Safety LSO Engineer	When non-standard controls are used, the effectiveness of those controls must be confirmed. In this case, follow-up monitoring to ensure the work was being performed in a safe and compliant manner was expected.	There was no follow-up or review of the work.	Due to the complexity of the system, the technician's training and experience were relied upon to perform the task safely. Follow up verification of the effectiveness of these controls were not considered necessary by the support personnel.
The Risk Assessment relied on expert based controls vs. standards based controls. There was no oversight of these controls to verify consistency or effectiveness	Maintenance Supervision Safety LSO Engineer	When non-standard controls are used, the effectiveness of those controls must be confirmed. In this case, follow-up monitoring to ensure the work was being performed in a safe and compliant manner was expected.	There was no follow-up or review of the work.	Due to the complexity of the system, the technician's training and experience were relied upon to perform the task safely rather than standards based instructions in the work order.

Appendix C

Events and Causal Factor Chart

Appendix D

Photographs

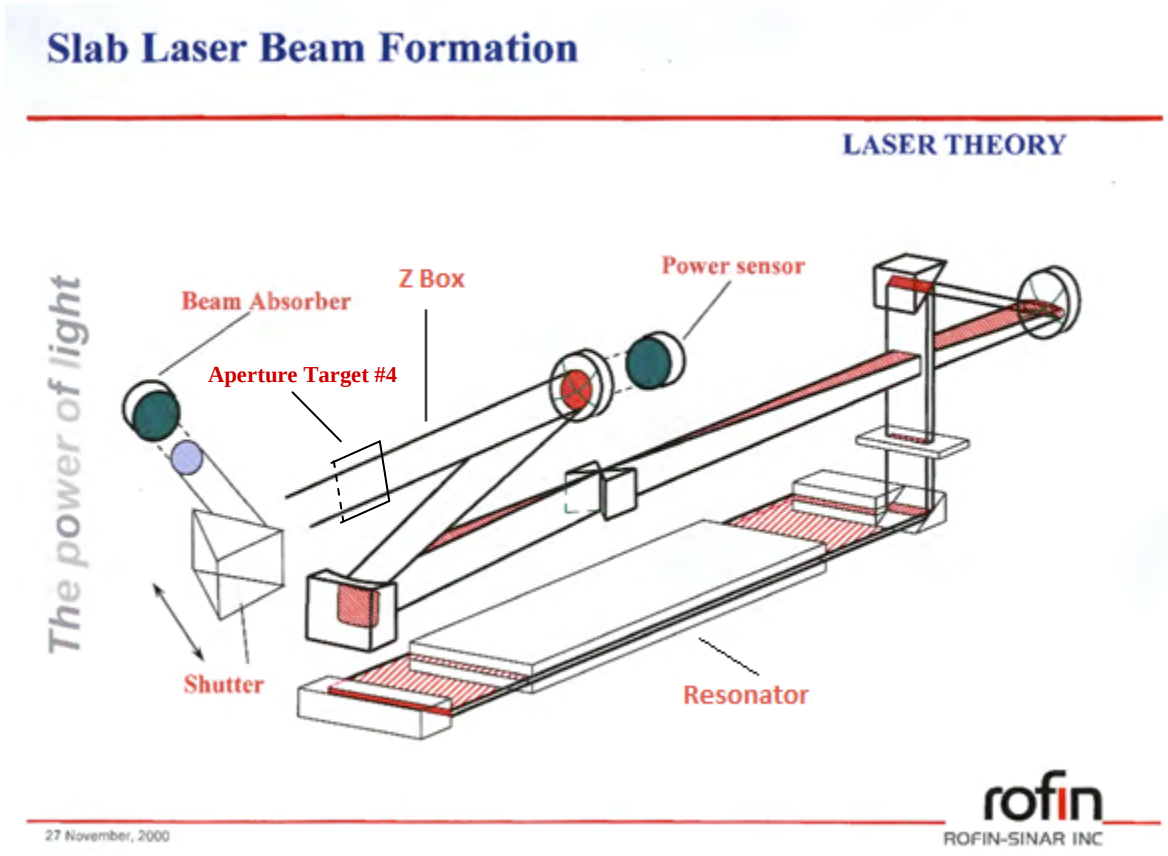

Figure 1. Slab Laser Beam Formation.

Figure 2. HMI Control.

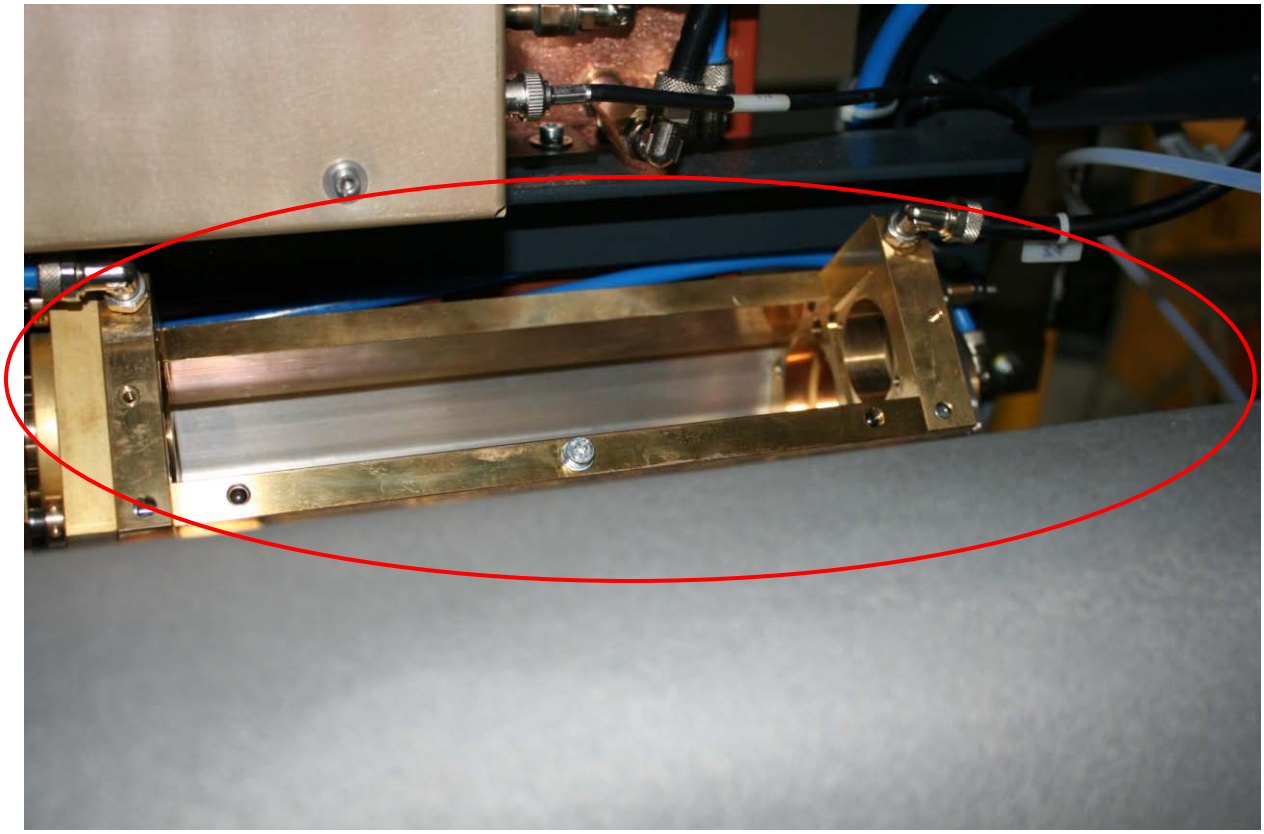

Figure 3. Z Box.

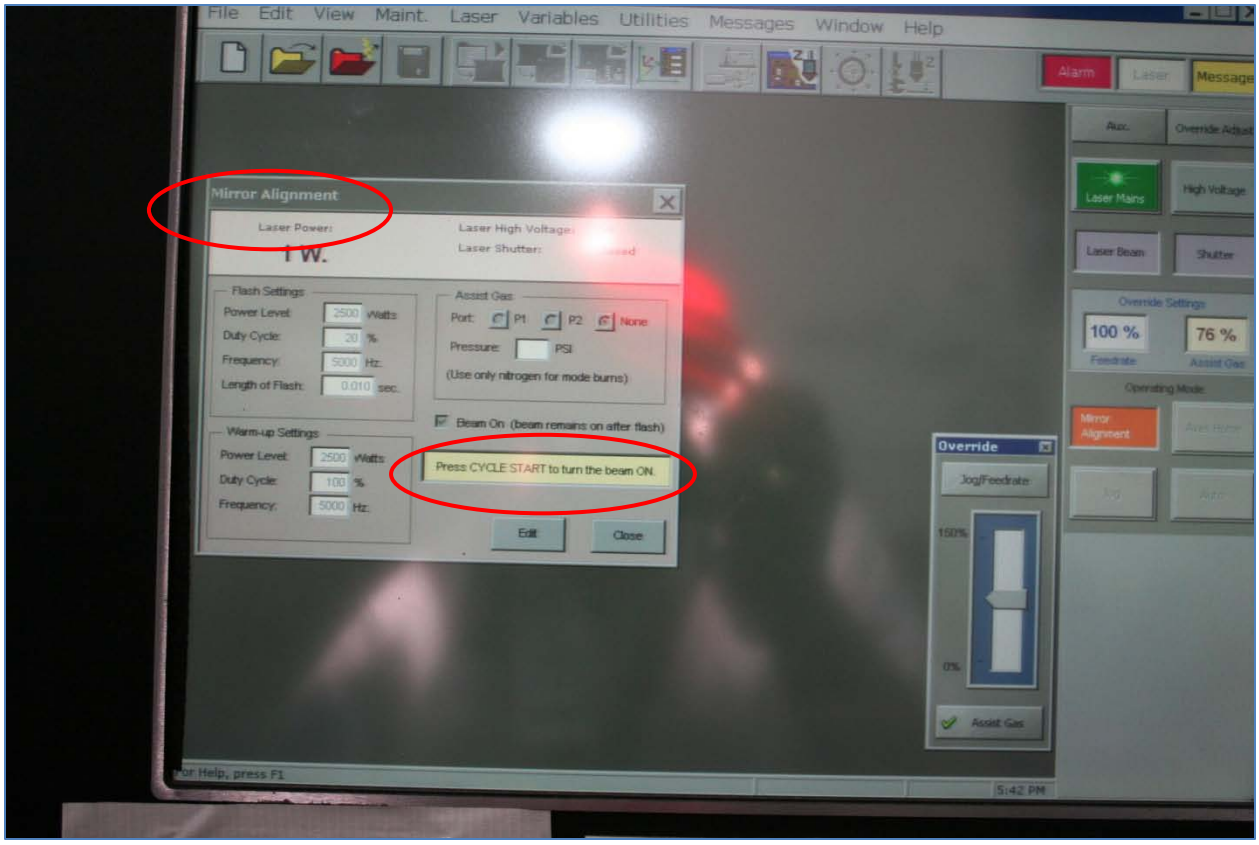

Figure 4. HMI Screen.